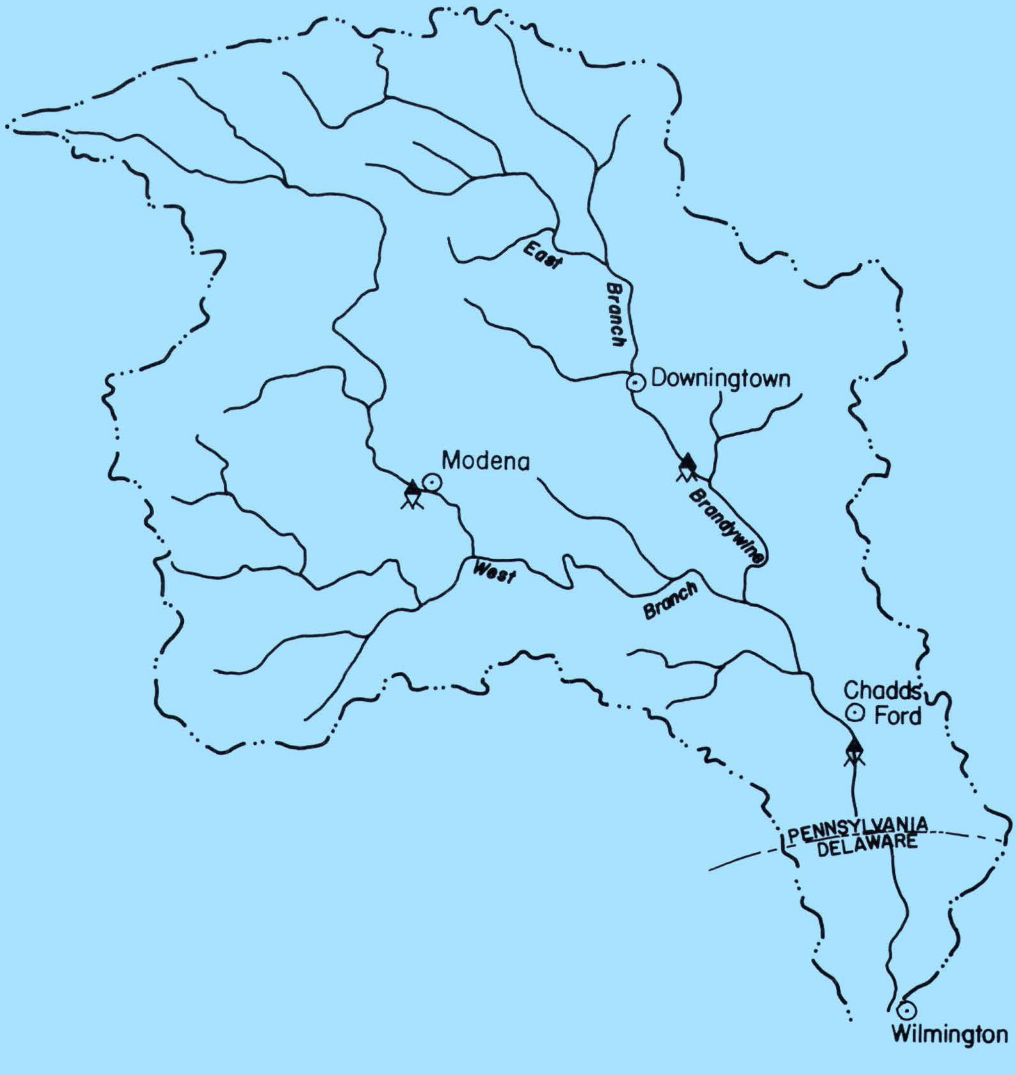
An Evaluation of Water-Quality Monitoring in the Brandywine Creek Basin, Pennsylvania, 1973-78

U.S. Geological Survey

Open-File Report 81-1115



AN EVALUATION OF WATER-QUALITY MONITORING IN THE BRANDYWINE CREEK BASIN, PENNSYLVANIA, 1973-78

By John J. Murphy, John R. Ritter,
Ann E. Brown, and Joseph P. Chiarella

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FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM (SI) UNITS

Multiply inch-pound unit	By	To obtain SI units
cubic foot per second (ft^3/s)	2.832×10^{-2}	cubic meter per second (m^3/s)
square mile (mi^2)	2.590	square kilometer (km^2)
degree Fahrenheit (°F)	°C = (°F-32)x5/9	degree Celsius (°C)

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ABSTRACT

Data recorded from 1973 through 1978 by monitors on West Branch Brandywine Creek at Modena, East Branch Brandywine Creek below Downingtown, and Brandywine Creek at Chadds Ford were analyzed to evaluate the effectiveness of the monitors in describing water-quality conditions. The data show that the stream at Modena and below Downingtown had periods of low dissolved oxygen, and that the stream below Downingtown had a particularly severe dissolved-oxygen deficiency from May through September 1974. The pH at all three sites exceeded 9.0 at times and the pH below Downingtown occasionally dropped below 6.0. The most critical period in the basin was from March to November when pH was most likely to exceed water-quality standards and dissolved oxygen was most likely to fall below the standards. Without the monitors, the extent and magnitude of these problems would not have been detected.

INTRODUCTION

The Brandywine Creek basin, lying mostly within Chester County in southeastern Pennsylvania, has a drainage area of 314 mi^2. The creek which has two major tributaries, the East Branch and West Branch (fig. 1), flows southeastward to Wilmington, Delaware, where it joins the Christiana River, before emptying into the Delaware River.

The U.S. Geological Survey (USGS) in cooperation with Chester County Water Resources Authority has maintained continuous water-quality monitors in the basin since June 1966 when a monitor was installed at Chadds Ford to measure specific conductance and temperature. During the 1972 water year[1/] (W.Y.), pH and dissolved-oxygen probes were added to the monitor. A monitor was installed on the West Branch Brandywine Creek at Modena in May 1971, and on the East Branch Brandywine Creek below Downingtown in February 1972. Both measured the same four characteristics measured at Chadds Ford. The Modena monitor was discontinued in October 1977; the other two are still in operation (1980).

1/A water year is the period October 1 through September 30 and is designated by the calendar year in which it ends.

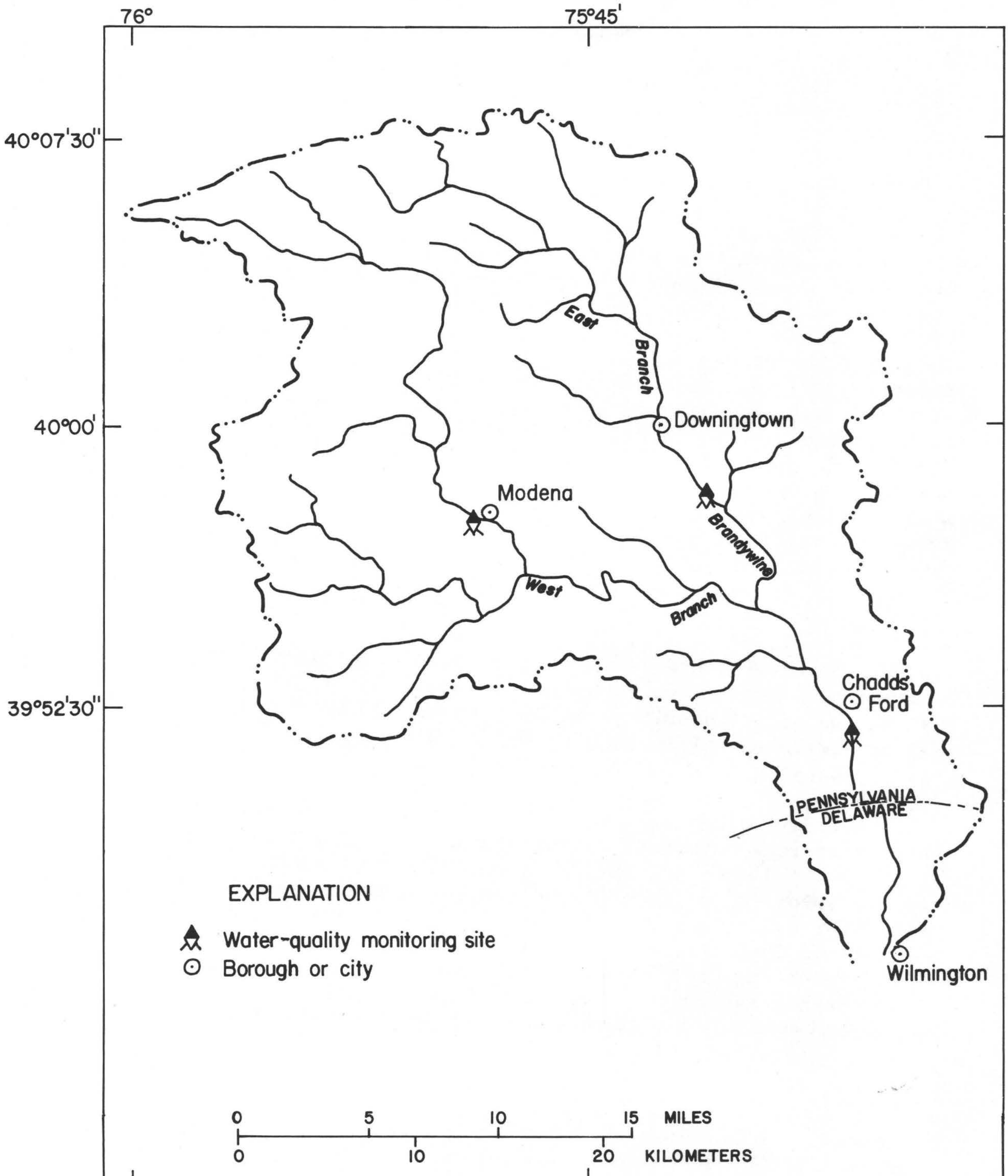

Figure 1.--The Brandywine Creek basin.

PURPOSE

The purpose of this report is to summarize the data measured by the monitors in the Brandywine Creek basin for the 1973-78 water-years and to determine the (1) adequacy of the data to indicate the water-quality conditions of the stream; (2) necessity of collecting these data by continuous-recording monitors; and (3) need to modify the monitoring system to measure additional water-quality characteristics, or delete characteristics already being measured.

PREVIOUS INVESTIGATIONS

Water-quality monitoring is only one of several activities the USGS has undertaken in the Brandywine Creek basin. Reports by USGS have been published on a wide range of topics, including general hydrology and water resources of the area (Parker and others, 1964; Miller and others, 1971); ground water (Poth, 1968; McGreevy, 1974; McGreevy and Sloto, 1976 and 1977); the 1971 flood (Page and Shaw, 1973); geomorphology and sediment transport of Brandywine Creek (Wolman, 1955; Guy, 1957); limnology of the basin (Lium, 1976 and 1977) and streamflow (Olmsted and Hely, 1962; Hely and Olmsted, 1963). Currently (1980) the rainfall-runoff relationships of the West Branch Brandywine Creek are being modeled. In addition, 12 stations in the Brandywine Creek basin are being sampled each fall, as part of the county's 50-station limnological program.

MONITORS

Monitors provide a continuous record of water quality by measuring specific conductance, temperature, pH, and dissolved oxygen at set intervals.

The advantages of using a monitor instead of collecting periodic samples for analysis are:

1. The data are timely, especially when the monitor is connected to an electronic system that will relay the data from the monitor to the user.

2. The monitor measures water quality continuously, thereby providing a much more complete picture than samples taken once a month, a week, or even a day.

3. The monitor provides a record of when, how long, and by how much water-quality standards are exceeded.

The disadvantages of monitors are:

1. Monitors are expensive to operate. They must be visited frequently to keep them running properly.

2. Monitors measure a limited number of water-quality characteristics--at present only specific conductance, temperature, pH, and dissolved oxygen.

3. Monitors provide data only for a point in a stream. For a small stream, the data are probably representative of the cross section of the stream. However, the water quality may be considerably different across a large stream, and the data, therefore, may not be representative of that stream.

4. Monitor data indicate only the general water quality of the stream. For example, the data may show that a stream has low pH and dissolved oxygen, but they do not define what is causing the low pH and dissolved oxygen. This can be answered only by more detailed chemical analyses and more sampling areally. Nevertheless, monitors are excellent in providing an indication of the health of the stream.

Performance

One measure of the adequacy of a monitor's performance is the number of days that data were recorded. Table 1 shows that the percentage of days having record from 1973-78 ranged from 67 (pH below Downingtown) to 95 (specific conductance and temperature at Chadds Ford). At each station the specific conductance and temperature records were more complete than the pH and dissolved-oxygen records reflecting the fact that the latter are more difficult to measure in general. The records at Chadds Ford were better than those for the upstream stations.

Table 1.--Percentage of days of recorded water-quality data, 1973-78

Station	Specific conductance	Temperature	pH	Dissolved oxygen
West Branch Brandywine[1/] at Modena	83	92	80	69
East Branch Brandywine Creek below Downingtown	92[2/]	92[2/]	67[3/]	82[3/]
Brandywine Creek at Chadds Ford	95	95	89	81

1/ 1973-77
2/ Feb. 27, 1973-Sept. 30, 1978
3/ March 7, 1973-Sept. 30, 1978

Table 2 shows that, in general, the days of recorded data at the monitors increased from 1973-78. This improvement may be attributed to:

1. Changing types of monitors in the fall of 1976. The new monitors are easier to keep operating than the old ones.

2. Using local observers to visit and service the monitors. Local people are able to visit the monitors more frequently than USGS personnel who have to travel longer distances and have other duties. These observers have done an excellent job of keeping the monitors running.

3. Installing DARDC[2/] in the fall of 1977 that relays data directly from the monitor to the user; in this case, the Chester County Water Resources Authority and the Chester County Health Department. By knowing what is being recorded at the monitor, erroneous data often can be recognized, and the monitor repaired with little loss of record.

The monitors recorded data for more than 90 percent of the days in 1977-78. If the monitors continue to operate this well, the data recorded should be adequate to describe the general water quality of the stream.

RESULTS AND DISCUSSION

The period from 1973-78 was selected for analysis of the water-quality and streamflow records because of the coincidental operation of the monitors below Downingtown and at Chadds Ford. Analysis of the records from the Modena monitor is included for the period from 1973-77. The data used in this report were published by the U.S. Geological Survey in the annual series "Water Resources Data for Pennsylvania."

The data are summarized in three ways:

1. Average monthly values for the monitor at Chadds Ford to show the seasonal trends.

2. Annual maximums and minimums to show the annual variations.

3. Monthly maximum and minimums to show when the extremes of the water-quality characteristics are likely to occur.

As shown in tables 1 and 2, the records have periods without data. Therefore, the maximum values discussed may have been exceeded, and lower values than the minimums discussed may have been reached. These missing data may also bias the conclusions and interpretations drawn from the recorded data. Nevertheless, the data do allow comparisons to be made among years, months, and sites.

[2/]The use of a brand name in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

Table 2.--Number of days having recorded water-quality data at monitor sites in Brandywine Creek basin, 1973-78

Water year	Specific conductance	Temperature	pH	Dissolved oxygen
West Branch Brandywine Creek at Modena				
1973	342	350	345	307
1974	285	334	339	275
1975	201	320	149	86
1976	324	323	271	249
1977	357	360	360	345
East Branch Brandywine Creek below Downingtown				
1973	163[1]	165[1]	177[2]	149[2]
1974	355	350	209	311
1975	335	340	95	258
1976	334	340	182	301
1977	354	343	354	330
1978	340	342	341	329
Brandywine Creek at Chadds Ford				
1973	331	307	221	250
1974	355	350	314	270
1975	342	360	344	301
1976	361	361	353	298
1977	365	365	365	333
1978	339	348	346	329

[1]Monitoring began February 27, 1973
[2]Monitoring began March 7, 1973

Specific Conductance

Figure 2 shows the general trends of the recorded water-quality characteristics at Chadds Ford. The trends should be the same at the other two sites. Chadds Ford was selected because the data were the most complete.

Specific conductance, as shown in figure 2, was low during times of high flow and high during times of low flow. This is typical; ground water is the source of most low-flow water and usually contains more dissolved solids than overland runoff, which is the main source of high-flow water. Although variation will be attenuated, the inverse relationship between conductance and discharge will continue to exist, even if sewage is a significant part of the flow.

Table 3 presents maximum and minimum annual values of specific conductance. The minimum did not vary more than 50 micromhos at each monitor, but figure 3 shows that the maximums varied considerably and increased progressively at each site from 1973-77. The maximum annual values were consistently highest at Modena and lowest at Chadds Ford. This decrease is due to a dilution of dissolved solids as the water moves downstream during low flows.

Maximum and minimum monthly values are shown in figures 4-6. The minimum values did not vary much; a specific conductance of 100 micromhos, for example, might occur any month. The highest conductances at all three sites, however, occurred in the winter.

Temperature

Water temperatures, as expected, were highest in the summer and lowest in the winter (figs. 4-6). Maximum monthly temperatures were highest at Modena and the minimum monthly temperatures were also highest there except from December through February. The higher specific conductances and temperatures at Modena may indicate that industrial or municipal waste waters are affecting the water quality of the West Branch.

pH

The Pennsylvania Department of Environmental Resources (PaDER) (1979) has set water-quality standards for streams in Pennsylvania to protect the warm-water and migratory fishes. The standards for Brandywine Creek at Chadds Ford state that pH should not be less than 6.0 nor more than 9.0. The graph of the average monthly values at Chadds Ford (fig. 2) shows a fluctuation of only 0.4 units (7.2 to 7.6), the highest occurring in April, the month of lowest average specific conductance. This peak may be due to biological activity.

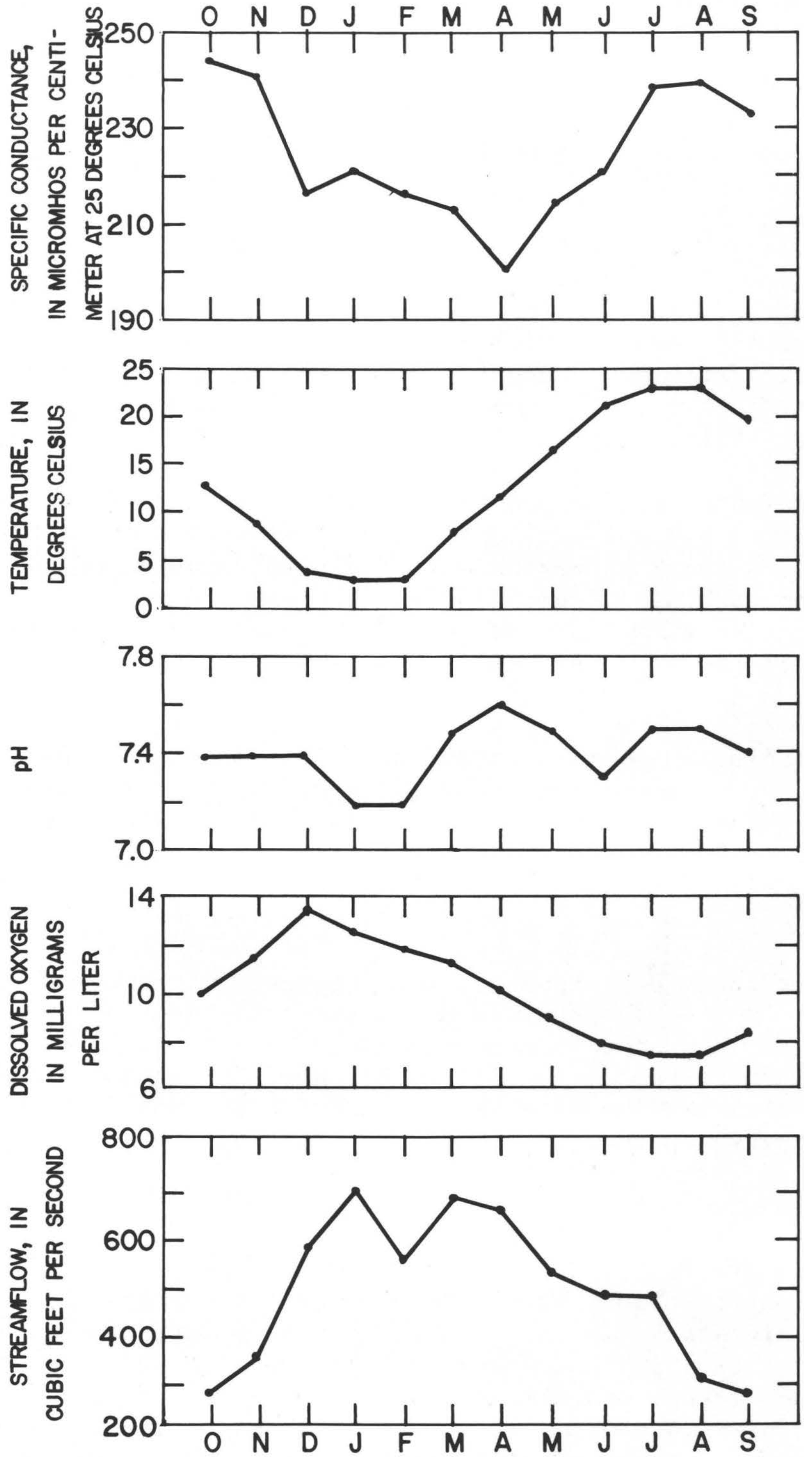

Figure 2.--Average monthly water-quality and streamflow data at Brandywine Creek at Chadds Ford, 1973-78.

Table 3.--Annual ranges of values of water-quality and streamflow data recorded at monitor sites in the Brandywine Creek basin, 1973-78

Water year	Specific conductance (micromhos/cm @ 25°C)	Temperature (°C)	pH	Dissolved oxygen (mg/L)	Streamflow (ft^3/s)
		West Branch Brandywine Creek at Modena			
1973	119 - 456	1.5 - 31.5	6.6 - 9.0	3.0 - 14.3	6.3 - 9,600
1974	132 - 503	3.5 - 33.0	6.5 - 9.8	2.1 - 14.1	0.66 - 2,280
1975	120 - 520	3.5 - 29.5	6.3 - 9.7	0.6 - 13.0	4.6 - 3,200
1976	105 - 705	0.0 - 30.0	6.5 -10.5	4.6 - 14.3	4.3 - 2,260
1977	88 - 858	0.0 - 33.5	6.8 - 9.3	2.8 - 16.3	8.0 - 1,710
Overall	88 - 858	0.0 - 33.5	6.3 -10.5	0.6 - 16.3	0.66 - 9,600
		East Branch Brandywine Creek below Downingtown			
*1973	115 - 343[1/]	2.0 - 30.0[1/]	6.2 - 9.9[2/]	2.6 - 14.4[2/]	29 - 6,870
1974	85 - 380	0.5 - 29.5	5.4 - 9.6	1.1 - 15.9	30 - 4,090
1975	125 - 401	1.0 - 28.0	6.3 - 8.5	4.2 - 14.8	36 - 3,250
1976	100 - 430	0.0 - 26.0	5.5 - 9.7	4.0 - 16.9	32 - 1,190
1977	107 - 652	0.5 - 33.0	6.7 - 9.0	2.6 - 16.3	23 - 2,220
1978	76 - 320	0.5 - 29.5	6.1 - 9.0	4.5 - 14.6	42 - 4,520
Overall	76 - 652	0.0 - 33.0	5.4 - 9.9	1.1 - 16.9	23 - 6,870
		Brandywine Creek at Chadds Ford			
1973	119 - 250	0.0 - 28.0	6.6 - 9.7	6.3 - 16.5	120 - 11,400
1974	127 - 326	0.0 - 27.0	6.4 - 9.1	5.4 - 15.3	122 - 6,790
1975	136 - 370	0.0 - 24.5	6.2 - 9.8	4.7 - 15.6	133 - 9,600
1976	139 - 397	0.0 - 26.5	6.1 - 9.2	3.9 - 15.5	104 - 5,200
1977	100 - 420	0.0 - 31.0	6.6 - 9.0	5.2 - 17.1	94 - 5,240
1978	89 - 271	0.5 - 28.5	6.6 - 9.0	5.3 - 15.2	118 - 15,700
Overall	89 - 420	0.0 - 31.0	6.1 - 9.8	3.9 - 17.1	94 - 15,700

[1/]Monitoring began February 27, 1973

[2/]Monitoring began March 7, 1973

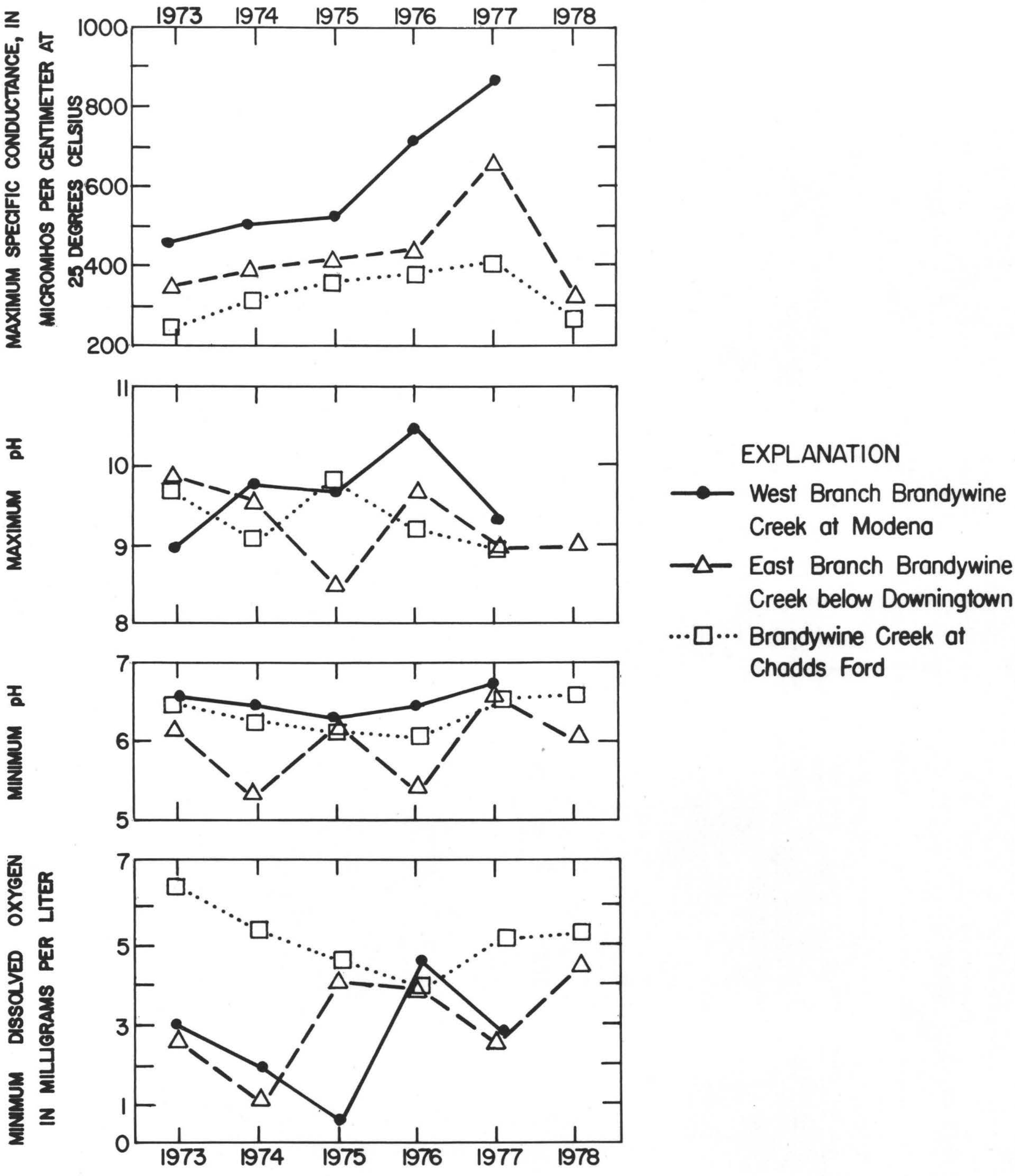

Figure 3.--Selected annual water-quality data measured at monitors in the Brandywine Creek basin, 1973-78.

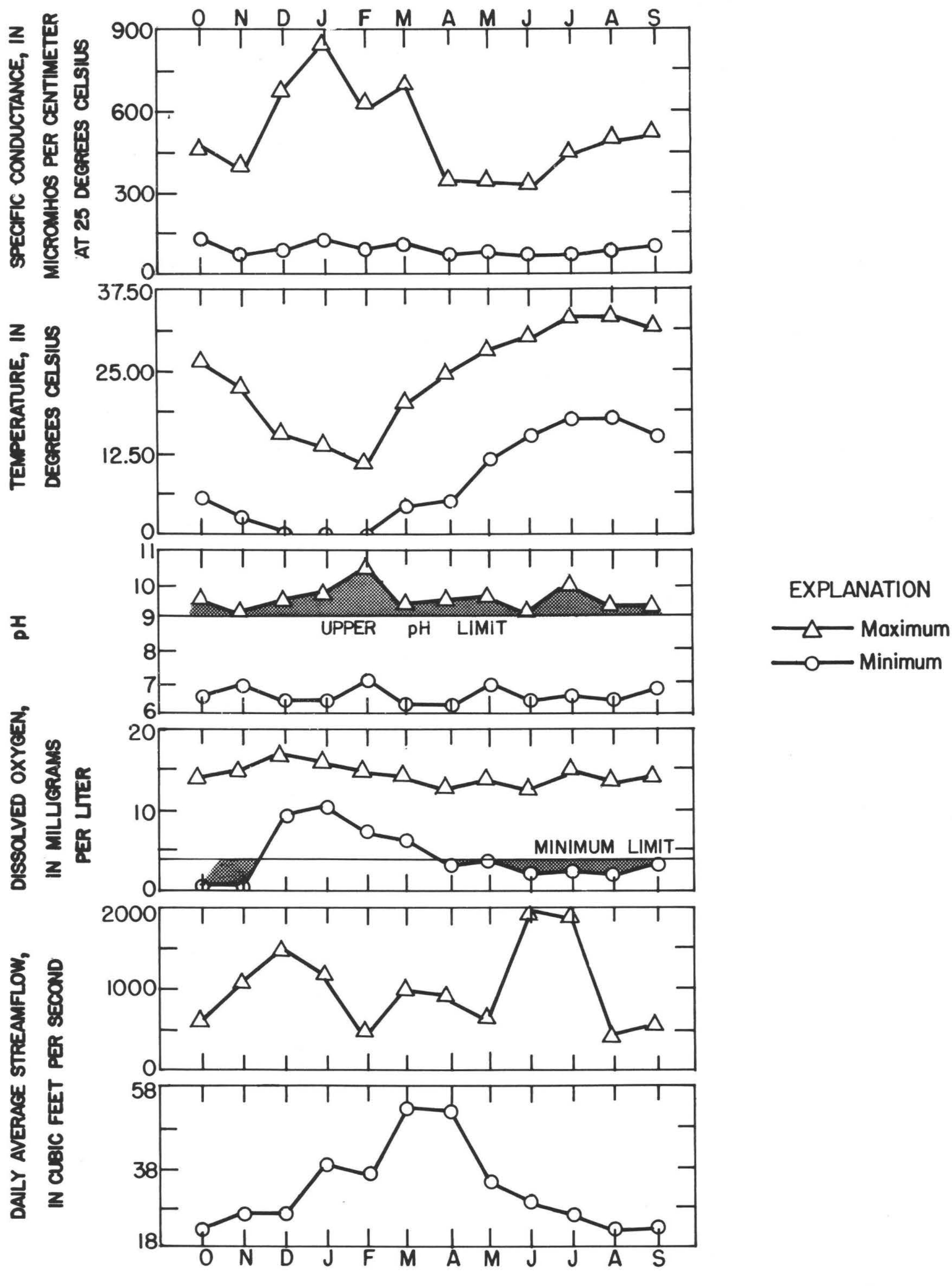

Figure 4.--Maximum and minimum monthly values of four water-quality characteristics and streamflow recorded at West Branch Brandywine Creek at Modena, 1973-77.

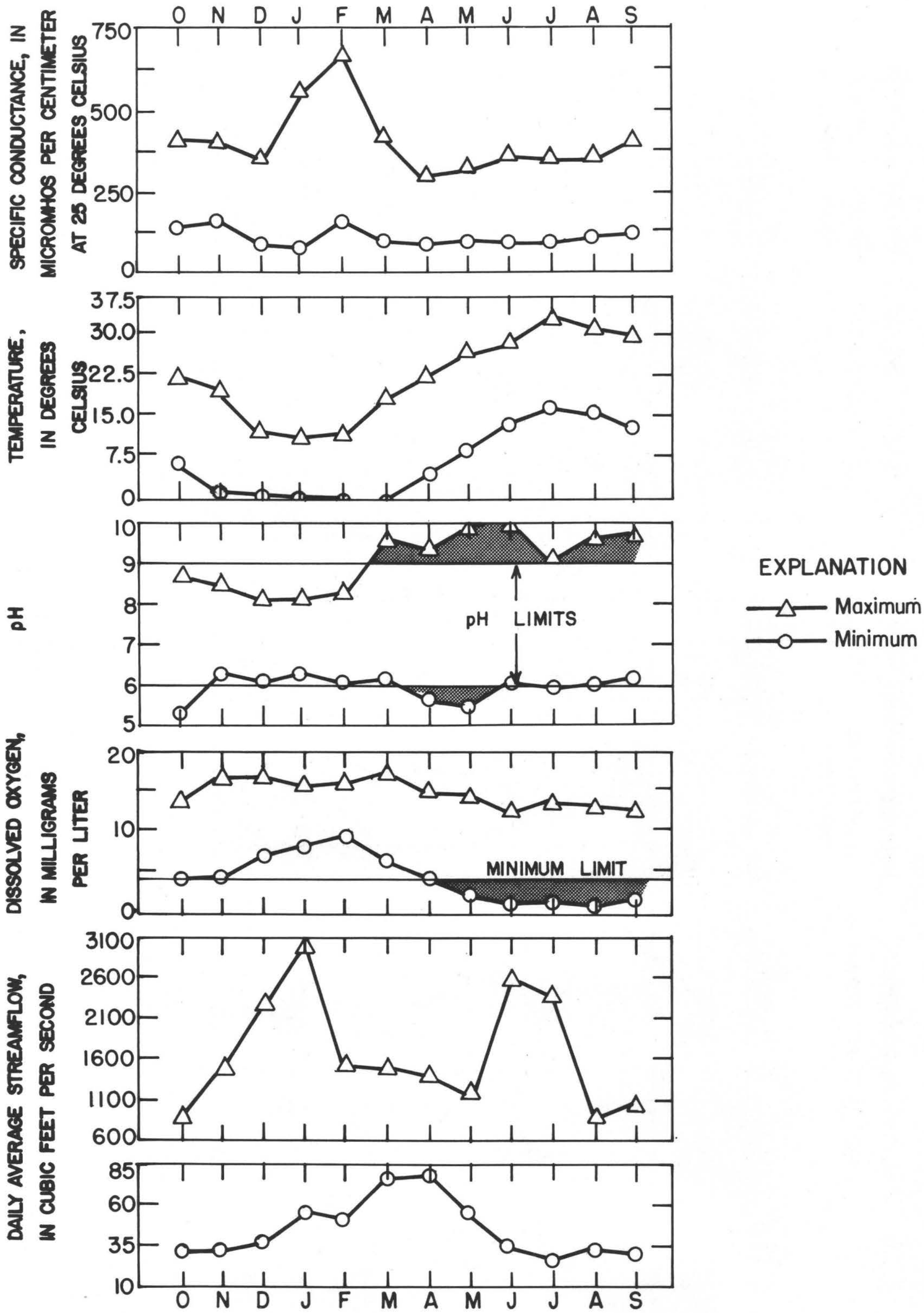

Figure 5.--Maximum and minimum monthly values of four water-quality characteristics and streamflow recorded at East Branch Brandywine Creek below Downingtown, 1973-78.

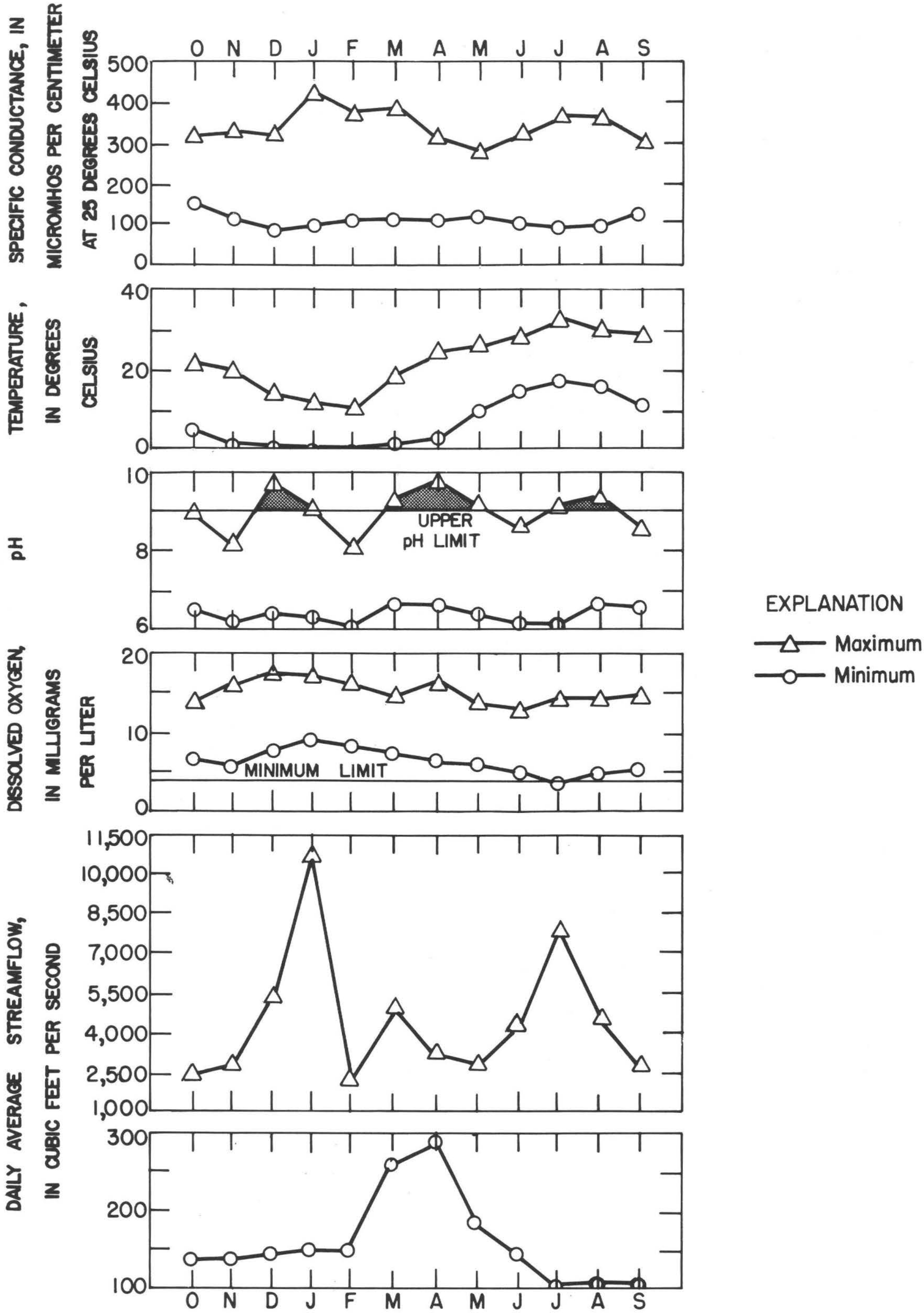

Figure 6.--Maximum and minimum monthly values of four water-quality characteristics and streamflow recorded at Brandywine Creek at Chadds Ford, 1973-78.

The lowest pH's each year were usually recorded below Dowingtown and the highest at Modena (fig. 3). The PaDER standard of 9.0 was exceeded at all three sites but not every year (table 3 and fig. 3). It was not exceeded below Downingtown and at Chadds Ford in 1977 and 1978; possibly an indication that whatever caused the high pH's at those sites (possibly algae) is no longer significant. The pH at the site below Downingtown was lower than the standard of 6.0 during 1974 and 1976. The graphs of daily maximum pH's for the years when the maximum standard was exceeded or minimum not met (fig. 7-8) show that the periods when the standards were violated did not last more than a few days, demonstrating the necessity for continuous monitoring.

The past records suggest that, although the standard of 9.0 may not be exceeded every year, it might happen any month at Modena, and is most likely to happen in the spring and summer below Downingtown and at Chadds Ford (figs. 4-6). The pH's of less than 6.0 below Downingtown occurred in October, April, and May.

Dissolved Oxygen

Concentrations of dissolved oxygen are typically lower in the summer, a period of high temperatures (fig. 2) because the solubility of oxygen in water is lower when water is warm than when it is cold. For example, its solubility is 11.3 mg/L at 10°C and 7.6 mg/L at 30°C (American Society for Testing and Materials, 1969, p. 820).

Water-quality standards for dissolved oxygen (Pennsylvania Department of Environmental Resources, 1979) at Chadds Ford are that the daily average should not be less than 5.0 mg/L, and no concentration should be less than 4.0 mg/L. Low concentrations of dissolved oxygen may be lethal to fish. Eggs and fry are less tolerant than adults, and the tolerance varies among species of fish (Mackenthun and Ingram, 1967, p. 46).

Except for 1 day in July 1976 (figs. 9c and 10c), the recorded dissolved-oxygen levels at Chadds Ford were higher than the minimum standards, and except for that year the minimum concentrations for each year were much higher than those at the other stations (fig. 3). Therefore, dissolved oxygen was not a problem at Chadds Ford.

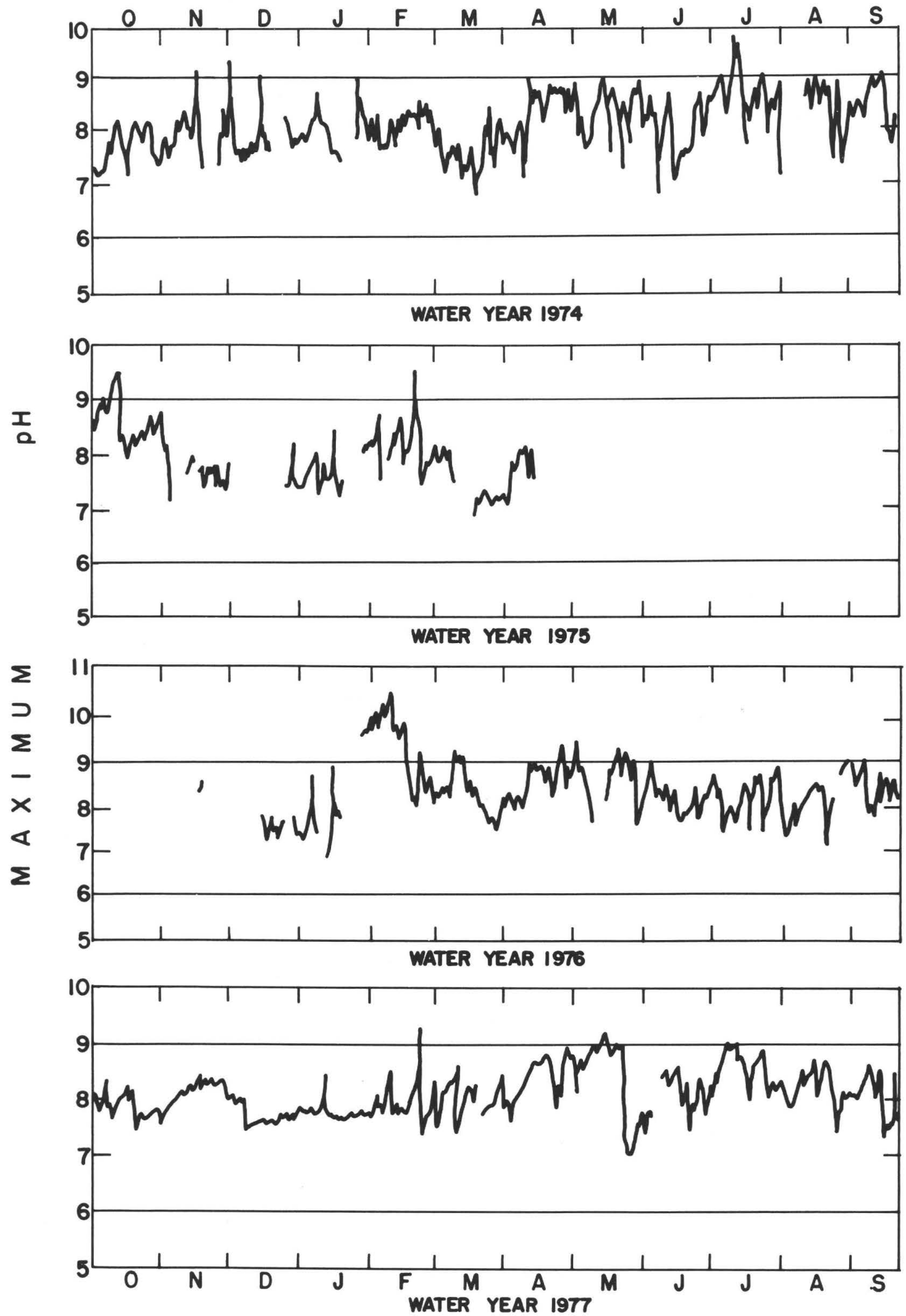

Figure 7a.--Daily maximum pH for years when pH of 9.0 was exceeded at times at West Branch Brandywine Creek at Modena.

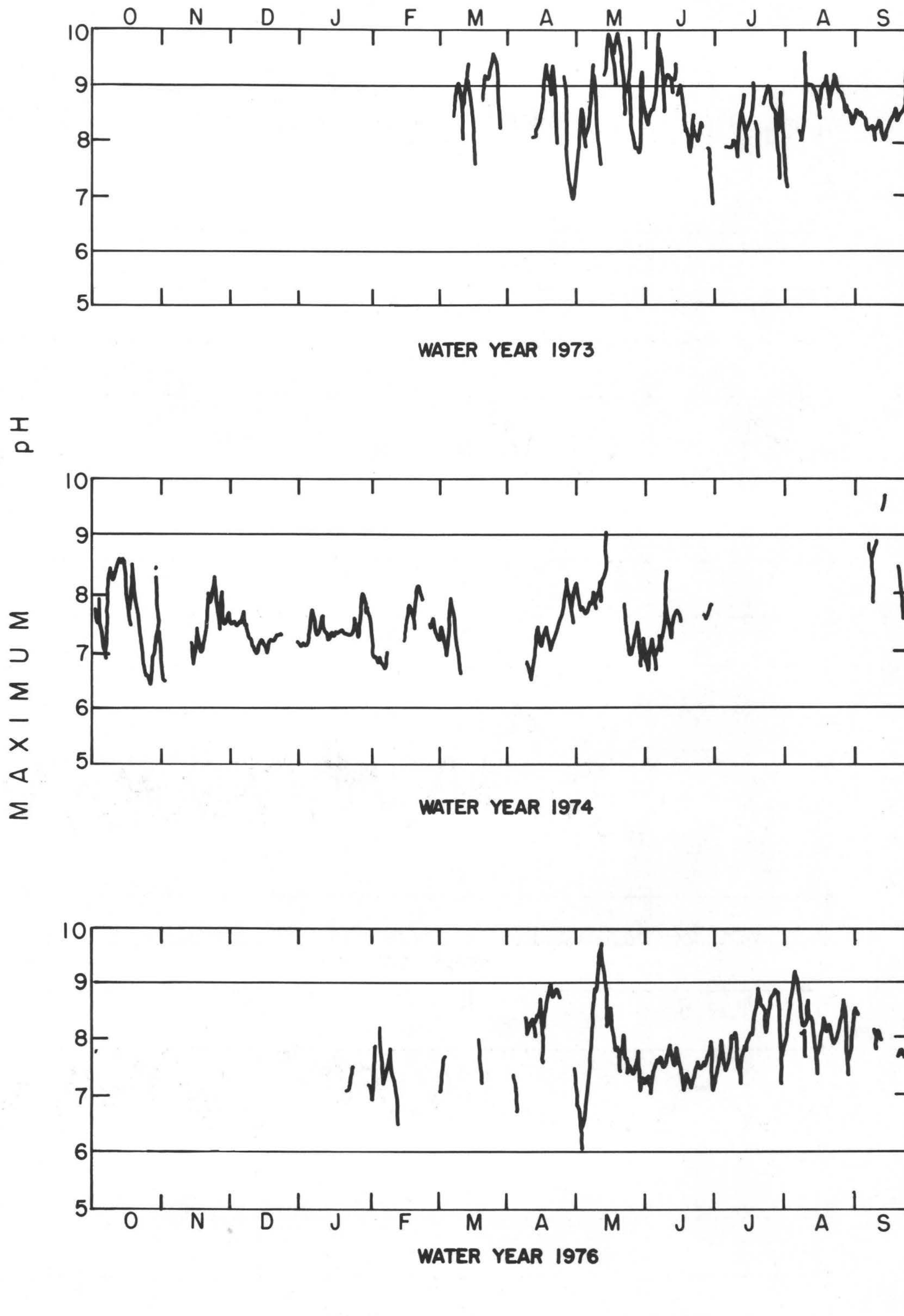

Figure 7b.--Daily maximum pH for years when pH of 9.0 was exceeded at times at East Branch Brandywine Creek below Downingtown.

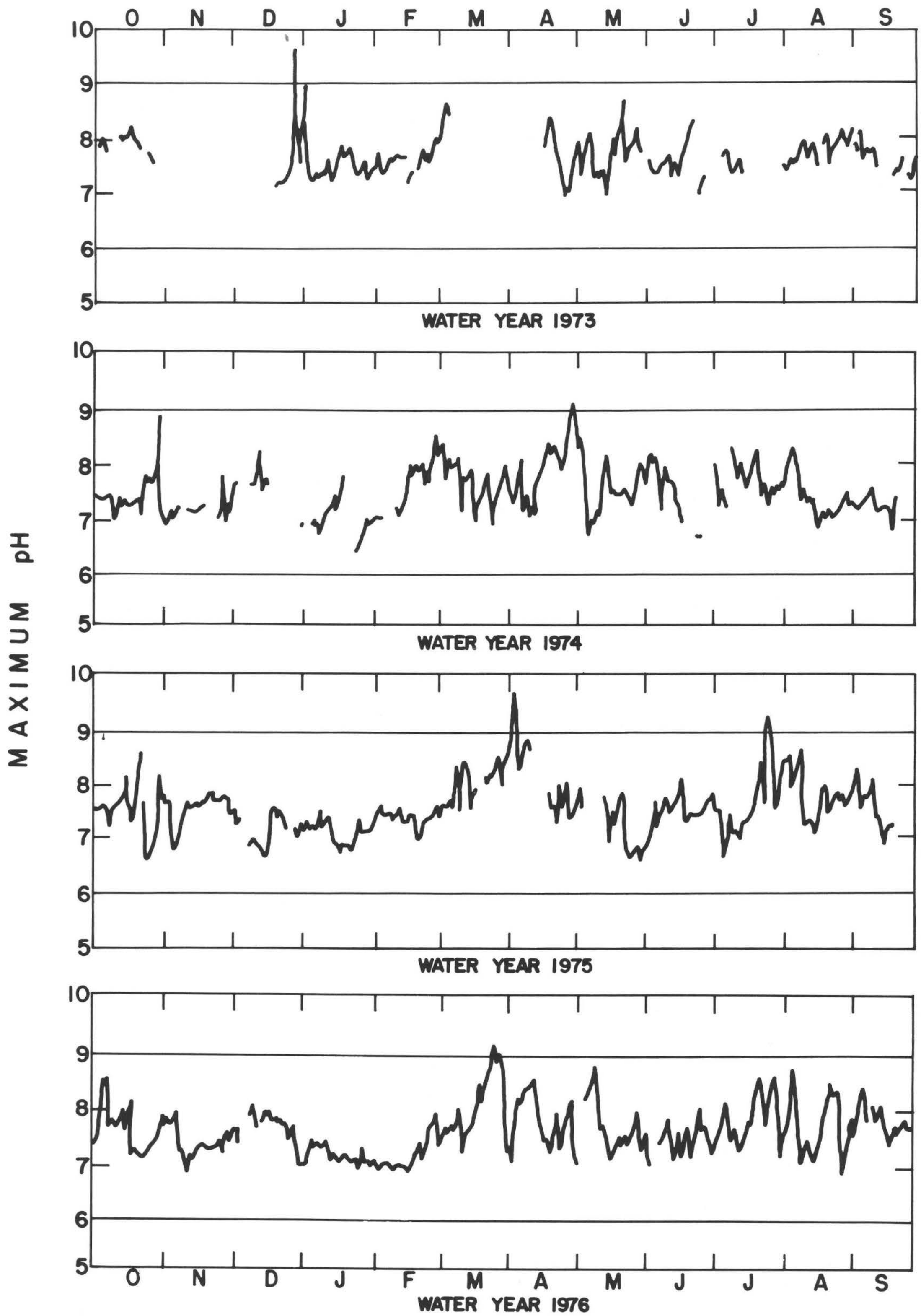

Figure 7c.--Daily maximum pH for years when pH of 9.0 was exceeded at times at Brandywine Creek at Chadds Ford.

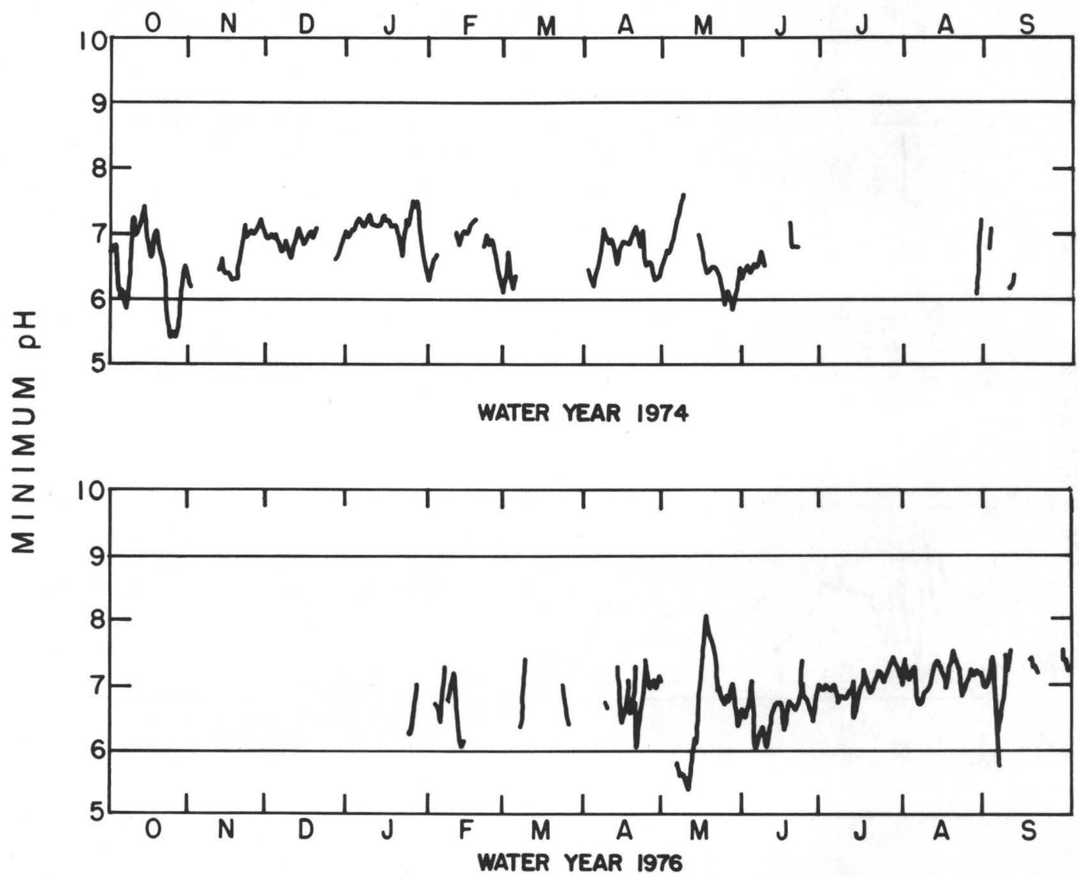

Figure 8.--Daily minimum pH for years when pH was less than 6.0 at times at East Branch Brandywine Creek below Downingtown.

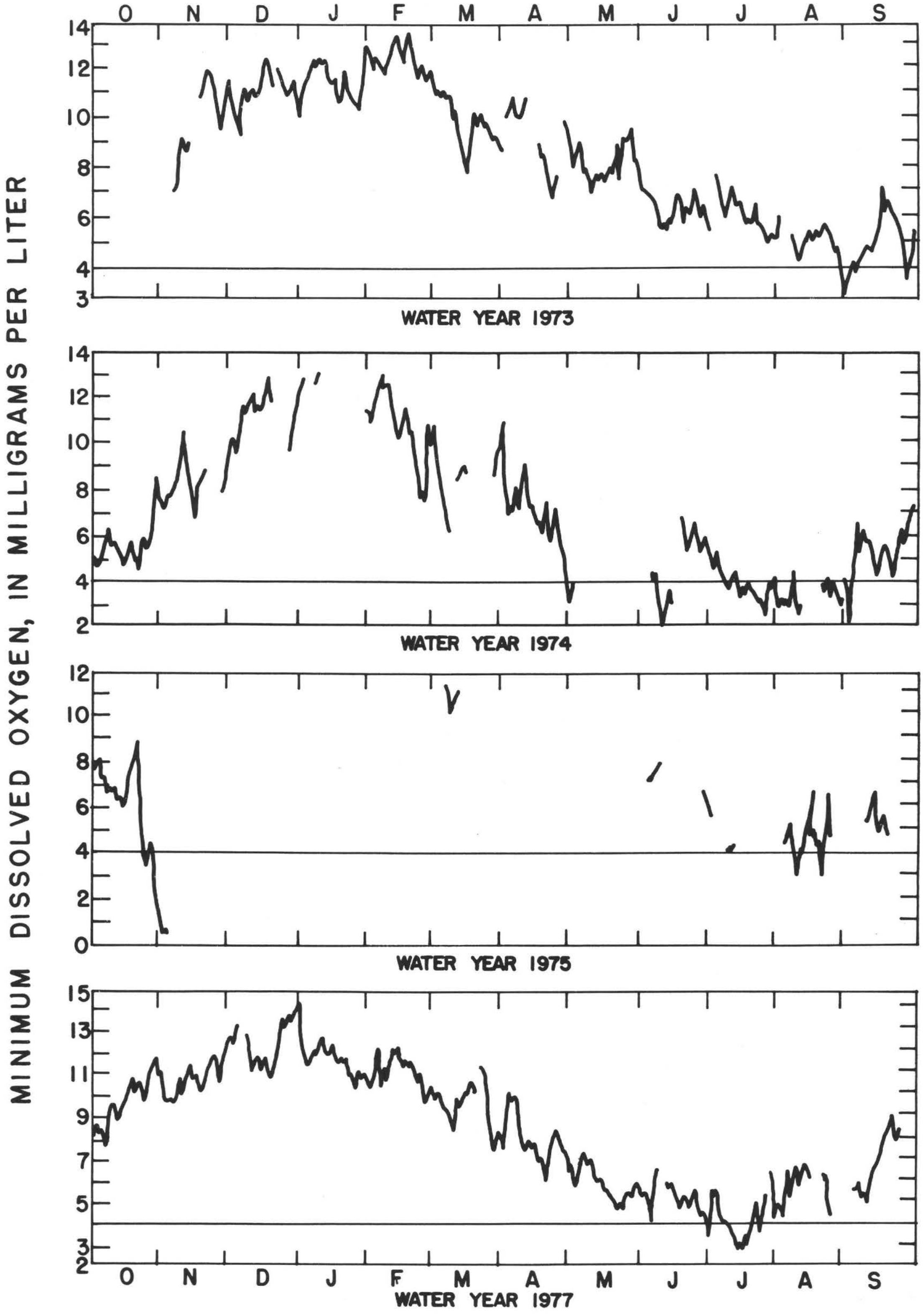

Figure 9a.--Daily minimum concentration of dissolved oxygen for years when the concentration was less than 4.0 mg/L at times at West Branch Brandywine Creek at Modena.

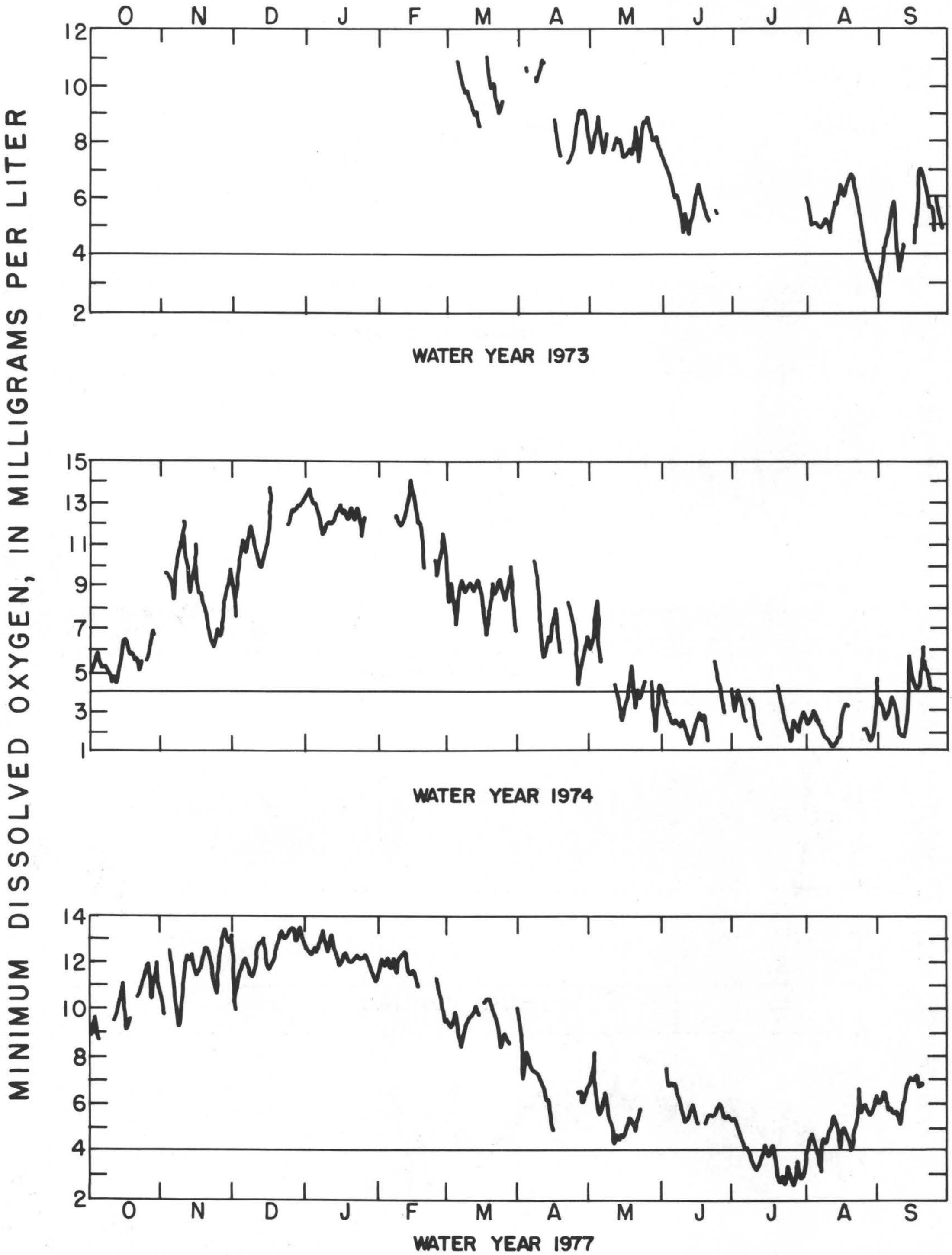

Figure 9b.--Daily minimum concentration of dissolved oxygen for years when the concentration was less than 4.0 mg/L at times at East Branch Brandywine Creek below Downingtown.

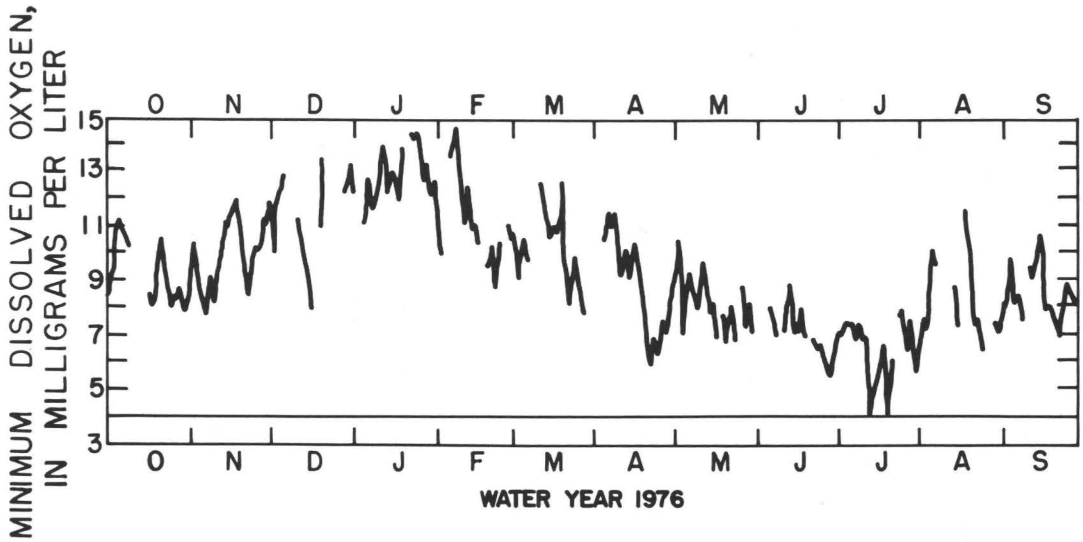

Figure 9.--Daily minimum concentration of dissolved oxygen for years when the concentration was less than 4.0 mg/L at times at Brandywine Creek at Chadds Ford.

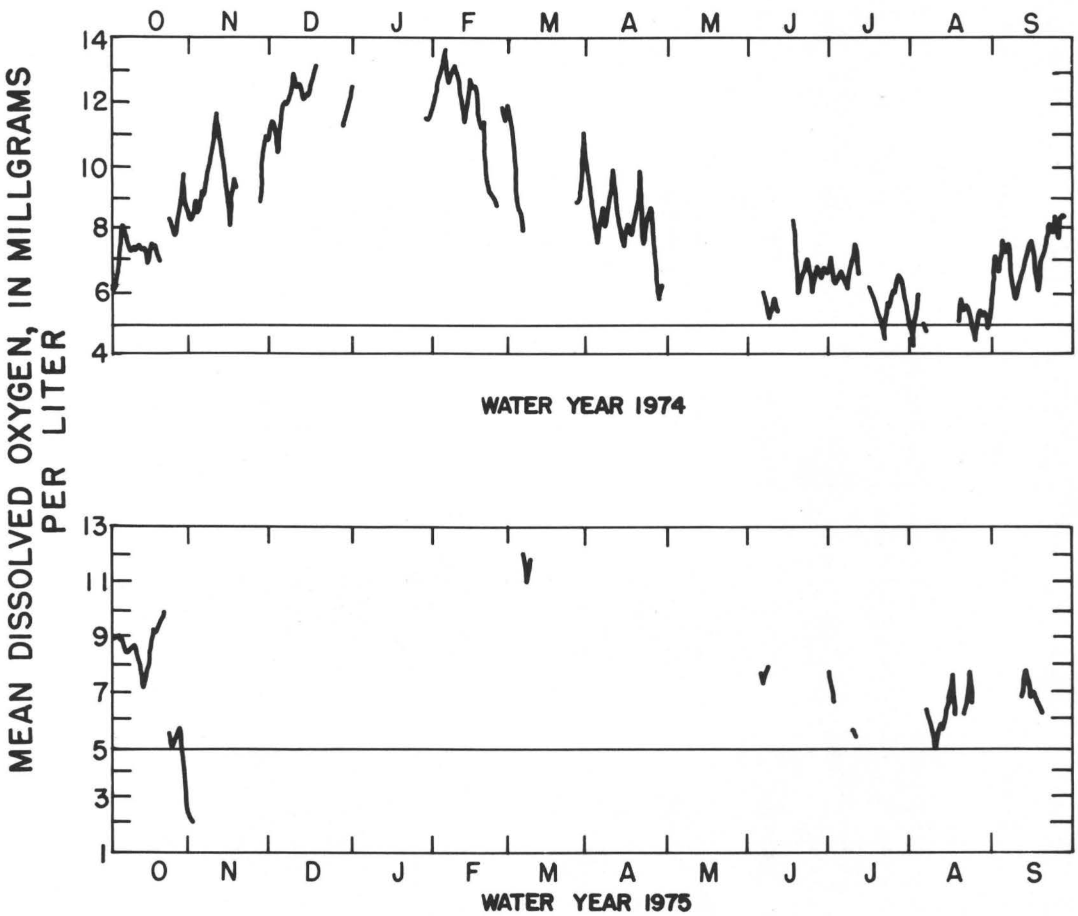

Figure 10a.--Daily mean concentration of dissolved oxygen for years when the concentration at times was less than 5.0 mg/L at West Branch Brandywine Creek at Modena.

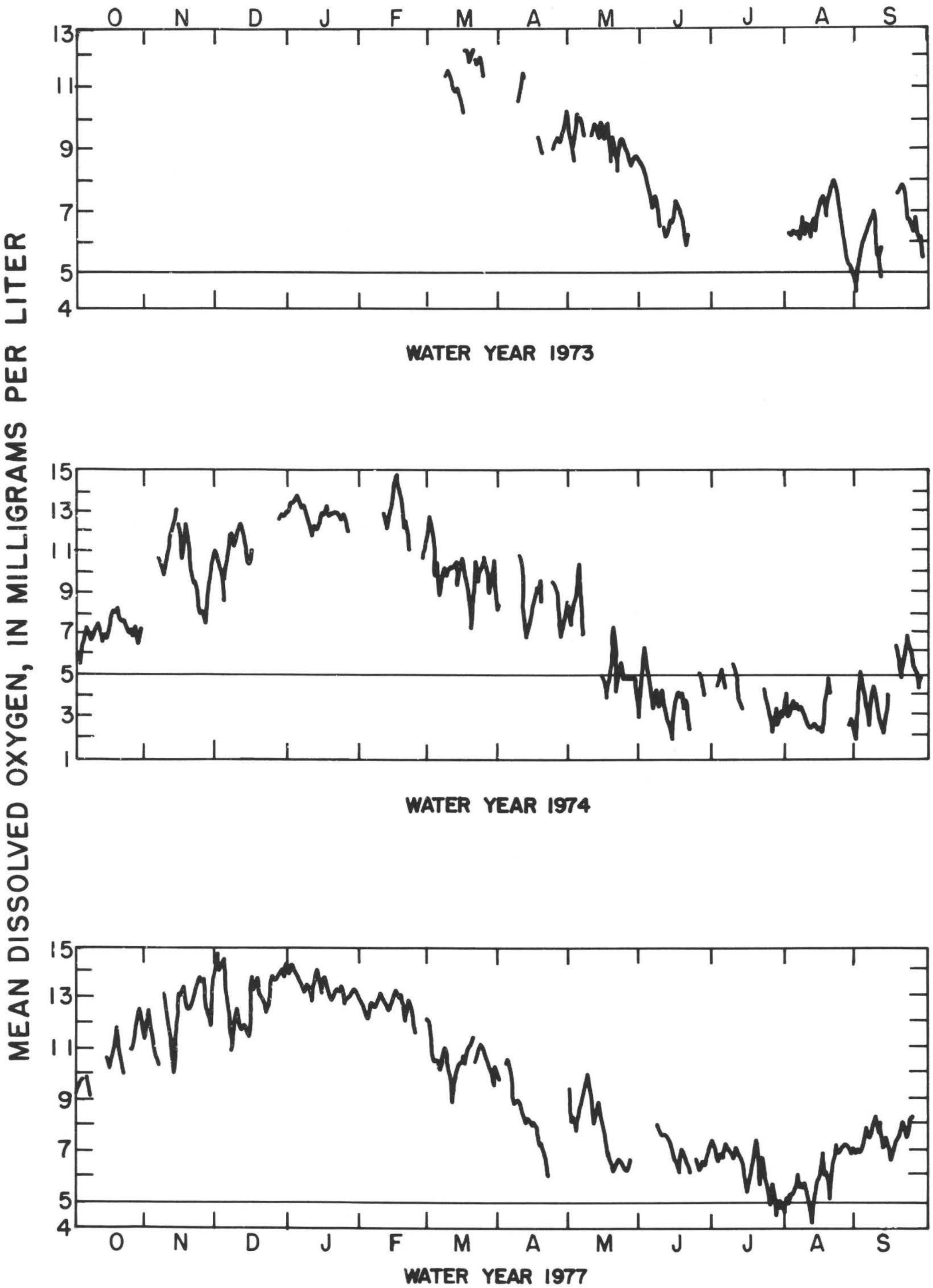

Figure 10b.--Daily mean concentration of dissolved oxygen for years when the concentration at times was less than 5.0 mg/L at East Branch Brandywine Creek below Downingtown.

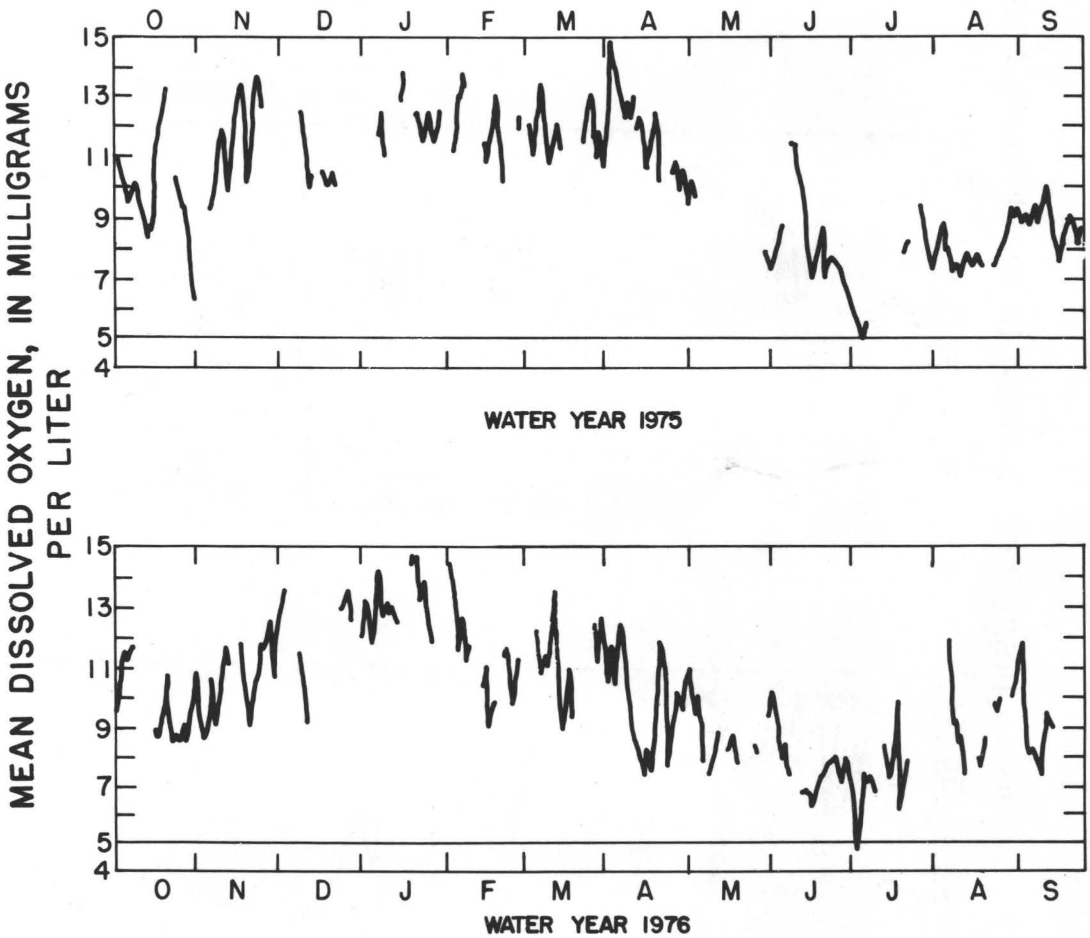

Figure 10c.--Daily mean concentration of dissolved oxygen for years when the concentration at times was less than 5.0 mg/L at Brandywine Creek at Chadds Ford.

The dissolved-oxygen level fell below the minimum criterion of 4.0 mg/L during 4 of the 5 years of record at Modena, and 3 of 6 years below Downingtown. Table 3 shows the number of days of record that the daily average concentration of dissolved oxygen was lower than 5.0 mg/L and the minimum concentration below 4.0 mg/L. It must be emphasized that, because dissolved oxygen was not recorded every day, the number of days shown in table 4 should be regarded as the minimum number of days the concentration was lower than the standard. From table 4, however, it can be seen that the East Branch below Downingtown had a prolonged dissolved-oxygen deficiency in 1974. The water in the East Branch was deficient in oxygen from mid-May through September of that year (figs. 9b and 10b). A condition this severe and long would probably impact the aquatic biota at that site. A short period of oxygen deficiency was recorded in 1977. Although the most prolonged oxygen deficiencies were recorded below Downingtown, the lowest concentrations were recorded at Modena in October and November 1974 (figs. 9a and 10a). The length of time that this deficiency lasted cannot be estimated because the monitor stopped recording dissolved-oxygen data in November.

Table 4.--Number of days recorded daily minimum and mean concentrations of dissolved oxygen were lower than 4 and 5 milligrams per liter, respectively

	West Branch Brandywine Creek at Modena		East Branch Brandywine Creek below Downingtown	
	Minimum	Daily mean	Minimum	Daily mean
1973	10	0	8	2
1974	43	7	96	87
1975	13	6	0	0
1976	0	0	0	0
1977	16	0	22	7
1978	--	--	0	0

Algal growth often affects the dissolved-oxygen concentration in streams. During late spring through early fall, a period of warmer temperatures and longer hours of sunlight, algal growth often is at a maximum. Dissolved-oxygen concentrations increase during the day because algal photosynthesis produces oxygen. Conversely, dissolved oxygen decreases at night when the algae respire and consume oxygen. The effects of algae on lissolved oxygen however cannot be determined from the monitor data.

Other possible causes of oxygen depletion are degradation of municipal and industrial wastes, which use oxygen, and releases of oxygen-depleted water from the bottoms of reservoirs.

Concentrations of dissolved oxygen below 4.0 mg/L are most likely to occur from April through November at Modena, and May through September below Downingtown (figs. 4-5), although these low concentrations will not occur every year.

Below Downingtown the oxygen depletion is most likely to occur when the flow is less than 100 ft^3/s and the water temperature is more than 18°C. At Modena the depletion usually occurs when the flow is less than 40 ft^3/s and the temperature is more than 18°C. These combinations are found in the summer.

CONCLUSIONS

Even though data are incomplete, they are adequate to demonstrate the extent of dissolved oxygen and pH problems on Brandywine Creek. The data collected in 1973-78 show that the water quality of the West Branch Brandywine Creek at Modena is probably the poorest of the three monitored sites. The highest pH and specific conductance and lowest dissolved oxygen were measured there. The East Branch below Downingtown had a long period of dissolved-oxygen deficiency in 1974 and a shorter period in 1977. It was also the only site where measurements of pH's lower than 6.0 were recorded. The only problem recorded on Brandywine Creek at Chadds Ford was high pH.

The most critical period in the basin is from March to November. During this time, pH and dissolved oxygen are most likely to exceed water-quality standards. Without the data that a monitor can supply, it would be difficult to determine how often poor water-quality conditions occur and how long they last. Monitors, however, only indicate these conditions and do not determine the causes.

The following can provide the necessary data to help determine the cause of the quality problems described above:

1. Continue operating the monitors below Downingtown and at Chadds Ford, especially from March through November. The monitor below Downingtown has detected periods of water-quality problems in the past. Chadds Ford has not had significant problems, but the monitor is valuable because it records information on the overall conditions of the stream.

2. Reestablish the monitor at Modena because the West Branch seems to have recurring water-quality problems.

3. Determine whether the causes of pH and dissolved oxygen problems are natural or man-made.

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